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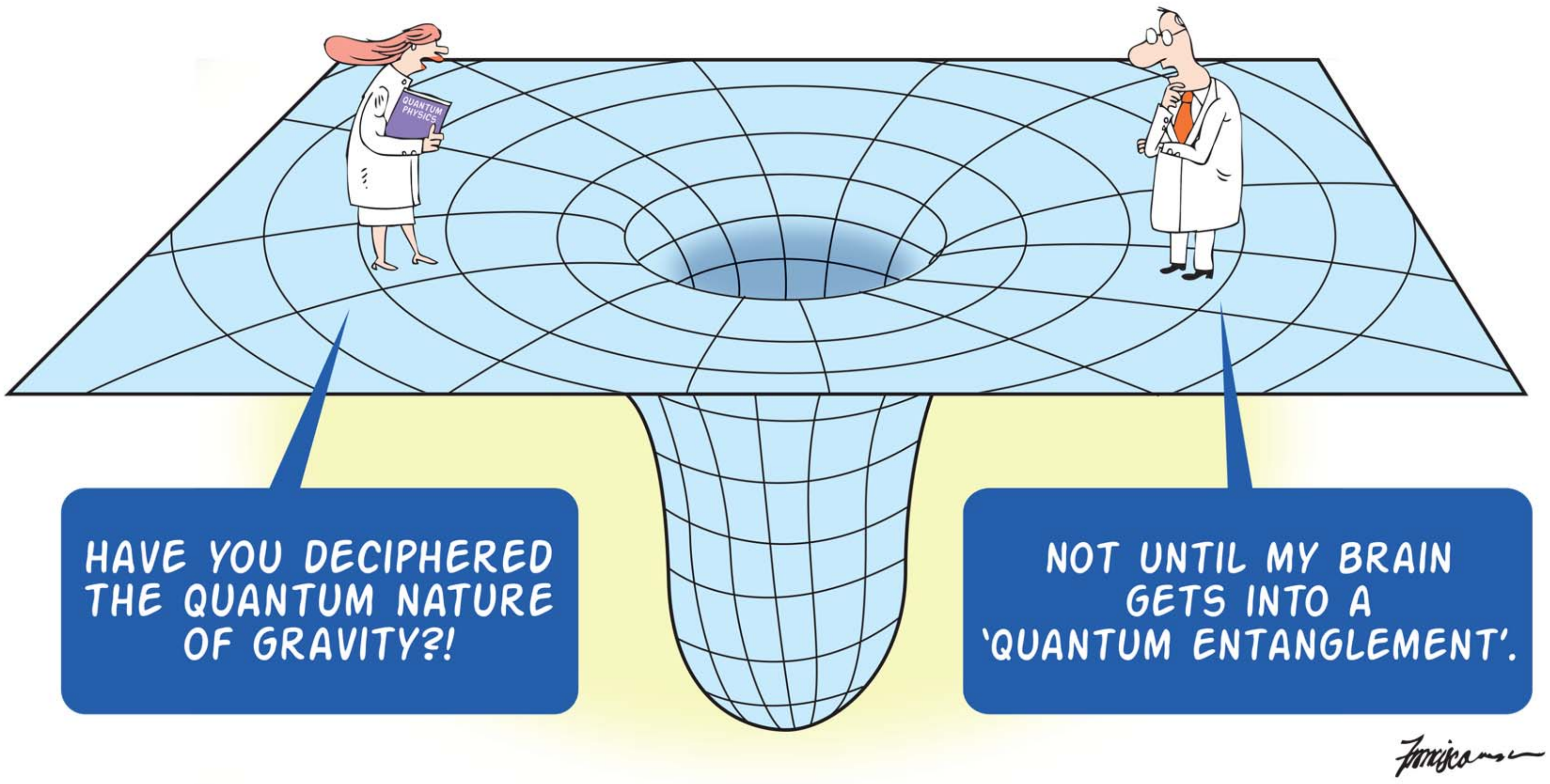

ScienceTalk

In search of the theory of everything

Finding a way to unify the laws of quantum physics with Einstein's general relativity

Vlatko Vedral

We take it for granted that gravity acts to keep us on the ground and to keep Earth in orbit around the sun.

But if we look at the atoms that make up our bodies, and at the smaller particles that make up those atoms, there's a mystery.

The problem is that small objects such as atoms and subatomic particles obey the laws of quantum physics, which are very different from the laws of gravity that govern the behaviour of large systems such as planets, stars and galaxies. Both quantum physics and Einstein's theory of gravity have been very successful in their own domains. But they just cannot be unified.

For theoretical physicists like me, this is a nagging problem. We can't ignore such a big rift in our understanding of how the universe works. We are intrigued by this unknown and want to unravel the mystery.

The main troublemaker is a principle of quantum physics, the superposition principle, stipulating that all objects can exist in two or more locations at the same time.

If that idea seems strange to you, don't worry: Scientists have proved that particles play this trick but we still argue over how they do it.

Gravity, on the other hand, can only be understood as a force emerging from an object that exists at only one well-defined position at any given time.

So what happens if you try to meld the two theories?

There are already some exciting predictions coming from the domains where both gravity and quantum physics matter.

The most stunning one is that black holes are not really black. According to Einstein's theory of gravity a black hole is such a massive and compact object that nothing can escape its gravitational grip. And this includes light, which is why they are called black holes.

However, when we try to understand black holes quantumly – the late and renowned physicist Stephen Hawking was the first person to do so in the early 70s – it transpires that they are capable of emitting light and other particles. This phenomenon, which is so small that it has not yet been observed, is known as the Hawking radiation.

But many people, including myself, remain unsatisfied. We have been hunting for other effects to measure. Hawking's result still uses ordinary Einstein gravity and quantum physics separately, and not as a unified theory of quantum gravity.

Other predictions have also proved extremely hard to test in practice – to the point that some even doubt that gravity can support quantum effects. This includes speculations that quantum physics will collapse when gravitational forces are strong enough. So I decided to start to imagine what it would mean to have gravity and quantum physics working together in one and the same domain, and be able to confirm that gravity is quantum experimentally. A breakthrough came last year when a colleague of mine, Dr Chiara Marletto, and I sketched out an experiment that would test the quantum nature of gravity.

If we put a massive molecule in two places at the same time, in a quantum superposition of two different locations, it would generate a gravitational force that cannot be described in Einstein's gravity.

However, Dr Marletto and I realised that we need not worry about this failing. If we put another massive molecule close by, then we would be able to probe the nature of the gravitational force generated by the first molecule being in two places at the same time.

No one has thought of using two quantum objects to probe the nature of gravity before.

Our amazing conclusion is that if the gravity that couples these two molecules together is indeed quantum, it would make the second molecule be in two different positions at the same time too.

Therefore, by testing if at the end of the experiment both molecules exist in two positions at the same time, a state known as quantum entanglement, we would reveal the quantum nature of gravity.

We have already been approached by several people who are interested in performing the test.

Many ideas about quantum gravity are untestable, so it is exciting to have an experiment that could be performed in labs today.

These are the first steps towards reconciling our best understanding of the microworld – quantum physics – with our best description of the macroworld – Einstein's general relativity.

What could be other consequences of quantum gravity? One is that quantum gravity would be transmitted across distances through particles called gravitons, the same way that the electromagnetic forces are transmitted through photons, particles of light. No one has detected gravitons yet, as they would be tiny and meagre, but some theories predict they could exist.

Also, our macroscopic intuition about causality would be violated. We expect that a TV switches on after we press the remote control. Pressing the remote control is the cause for the TV to switch on.

In classical gravity, there is a strict relationship between such causes and effects. Einstein's theory says that gravity is just a manifestation of the causal structure of events in the Universe, ordering them into causally connected and disconnected ones.

In quantum gravity, causes and effects could be reversed. The TV could go off before we touch the remote control. In fact, the two orders, TV goes off before or after the remote control was used, could even exist at the same time.

Quantum physics has already revolutionised our technology. It underpins modern electronics from computer chips to GPS, and it promises a new generation of devices for computing, communication and sensing.

For example, computers that run on quantum rules will be able to solve problems that are beyond the reach of existing classical computers, such as searching big data and cracking encryption. My colleagues at the Centre for Quantum Technologies in the National University of Singapore, along with university researchers and companies in many other countries, are working on ideas like these.

Unifying quantum physics with gravity could open new frontiers. It may lead to an even bigger transformation for humanity. One speculative idea is that a unified theory could enable us to design a universal quantum constructor, a machine that can perform any physical transformation of matter, including self-replication.

If humanity gives birth to such universal machines, it might help our civilisation endure in time.

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About the writer

Vlatko Vedral is a principal investigator at the Centre for Quantum Technologies and professor at the National University of Singapore. He has published more than 300 scientific papers in quantum physics and quantum computing and was in 2017 named among the world's most cited researchers. He was elected a fellow of the UK's Institute of Physics in 2017. He is the author of four textbooks and two popular books on physics. The latest one, From Micro To Macro, discusses the above topic at great length.